Multilayer Development for Extreme Ultraviolet and Shorter Wavelength Lithography

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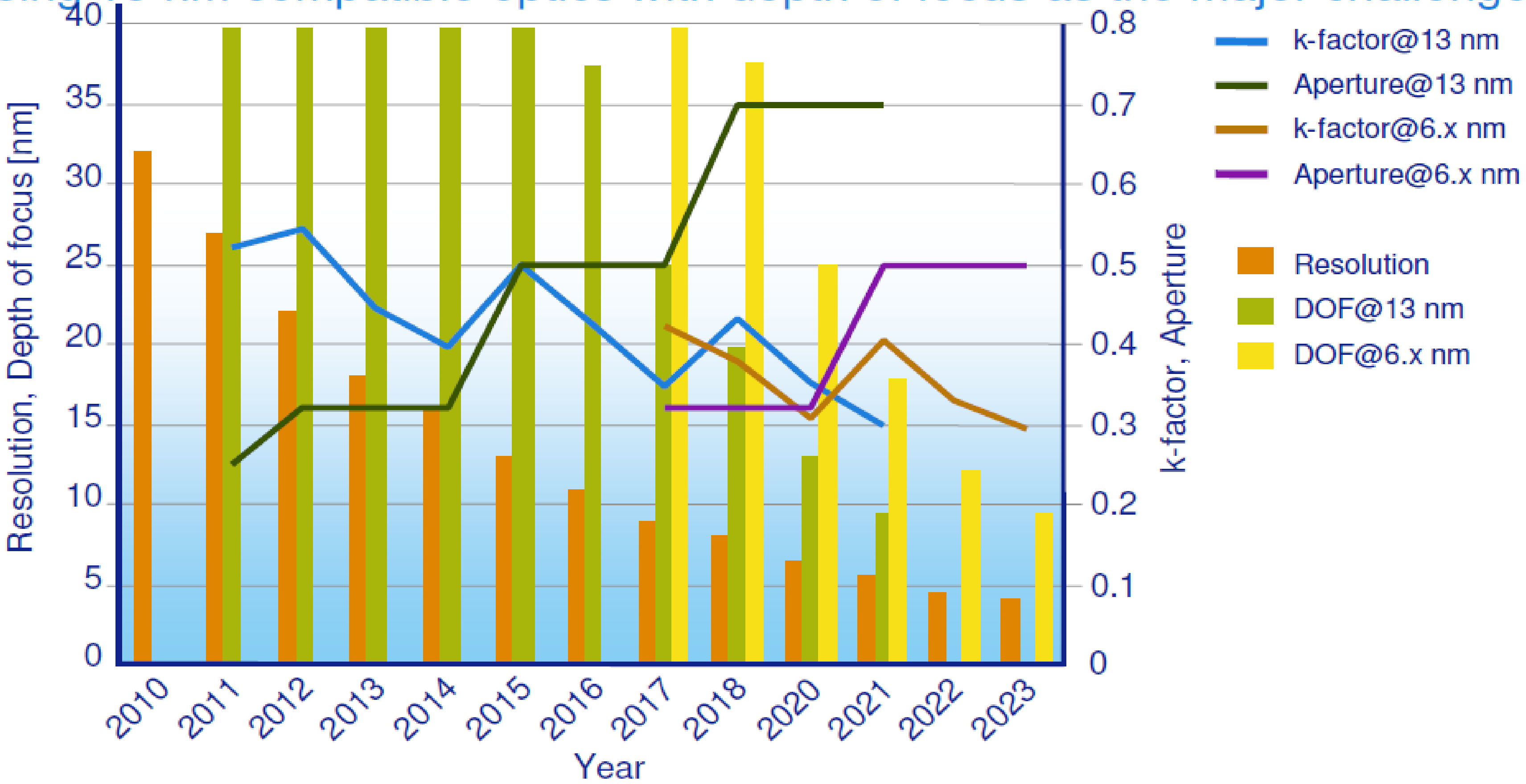
Opportunity to extend of EUV down to sub 5 nm possible

increasing apertures up to 0.7, wavelength reduction down to 6.8 nm using 13 nm compatible optics with depth of focus as the major challenge



ASML presentation: 2010 International Workshop on EUV Sources, Dublin, Ireland

ASML

Outline

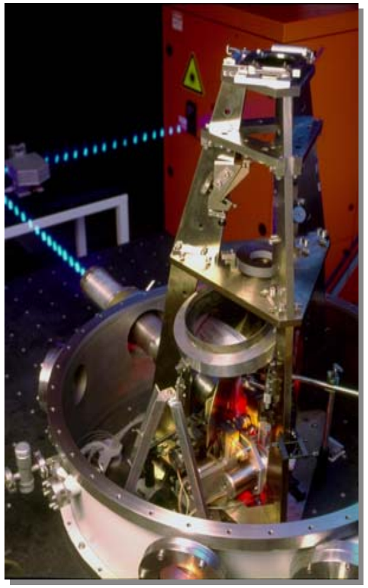
- FOM, who we are …
  - → 13.5 nm research
  - → Need for shorter wavelengths optics

- 6.x nm multilayer issues relevant for performance and choice of optimum operational wavelength
  - ❑ Passivation of La with Nitrogen
  - ❑ Roughness reduction
  - ❑ $B_4C \rightarrow B$

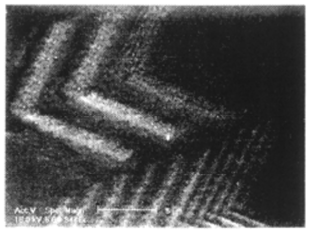
- Wavelength selection: multilayer reflectivity profile @ 6.5-6.9 nm

EUVL: from basic research → development labs

FOM pilot research on lithographic imaging using 13.5 nm (1992)



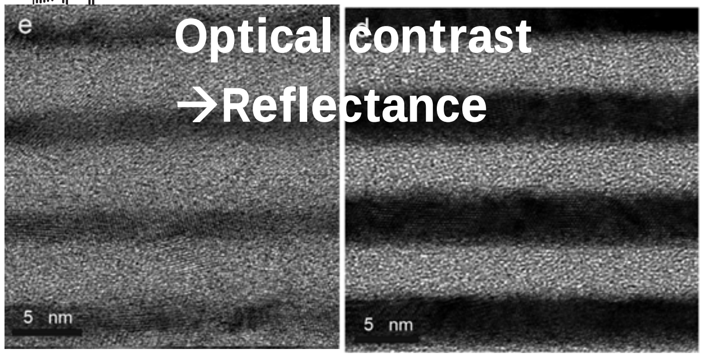
13.5 nm exposures in resist



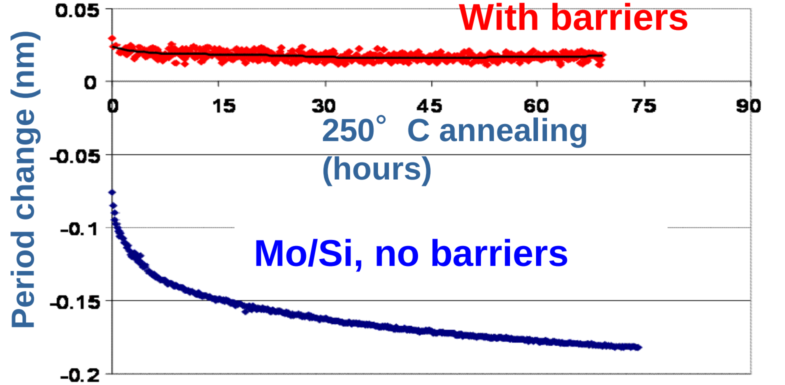
Two prototype 13.5 nm wafer scanners: ASML Alpha Demo Tools, ADT, including Zeiss and FOM ML-optics

λ	13.5 nm
NA	0.2
# Multilayer optics	10
Max diameter	45 cm
Resolution	~ diffraction limited

14 year of research on Mo/Si optics!



Increased thermal stability

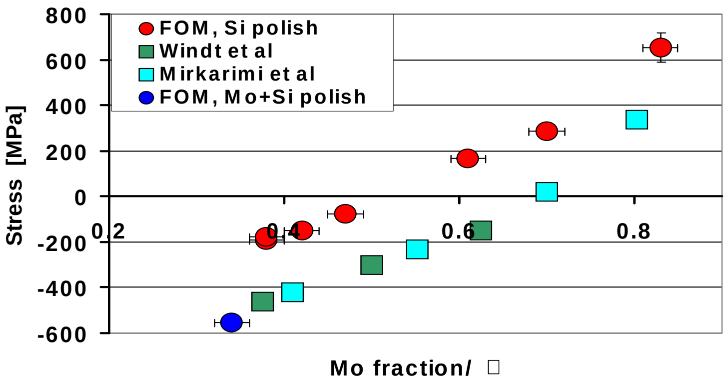


Coating uniformity

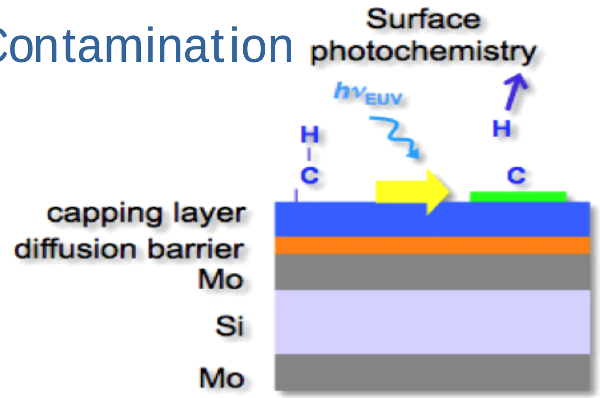
Periodicity control

Bandwidth

Stress reduction



Contamination



E. Louis et. al., Prog. Surf. Sci., doi:10.1016/j.progsurf.2011.08.001, 2011

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Downscaling λ to next generation EUV: 6.x nm

λ = 13.5 → 6.X nm

Novel ML coatings:

- New materials: Mo → La, Si → B (B_4C)
- Reduced bi-layer thickness: 6.8 → 3.4 nm

→ Requirements interlayer quality scale with λ

Baseline technology required:

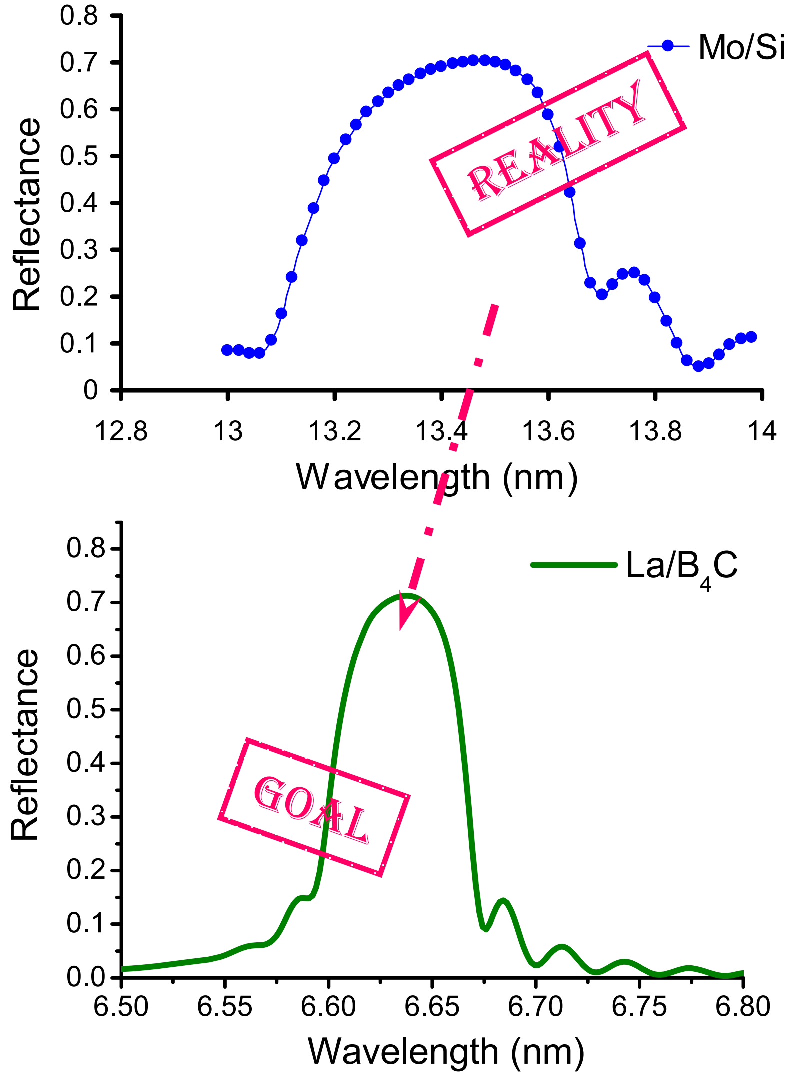
- ➢Reduction of layers intermixing
- ➢Roughness mitigation
- ➢Optimization of optical contrast

→ Search for optimal ML performance

Technological aspects:

Additionally to coating issues

- More bi-layers: @13.5 nm N=50 @6.x nm N~200
- Bandwidth of the optical column λΣ/λ(Mo/Si)=2% λΣ/λ(La/B)=0.6%



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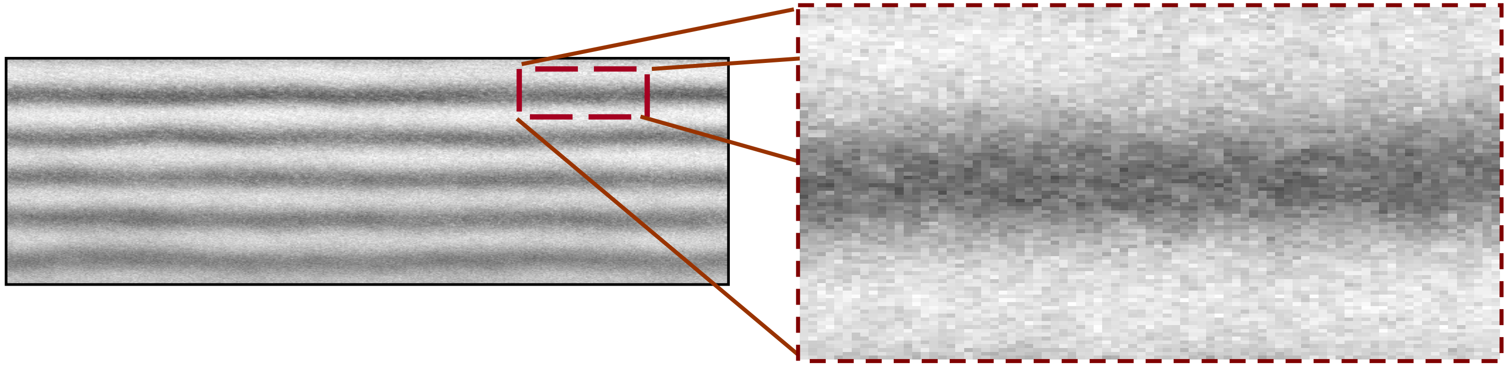
1st challenge: thermodynamics @ La/B_4C interfaces



The first TEM image → blurred interfaces are observed: La-B compound formation?

Compound	La	B_4C	LaC_2	LaB_6	LaN
ΔH^{for} (kJ/mol)	0	-71	-89	-130	-303

At interfaces: $7\ La + 6\ B_4C \rightarrow 4\ LaB_6 + 3\ LaC_2$ $(\Delta H = -305.4$ kJ/mole$)$

Solution: nitride formation can prevent La-B and La-C compound formation

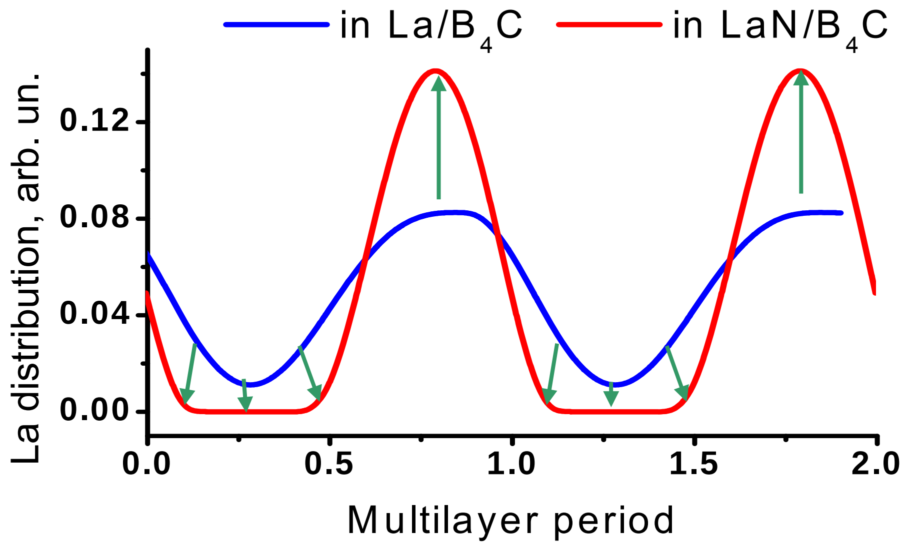
→ Introduce stable nitrides by N-ion treatment:

LaN can even enhance optical contrast [1]

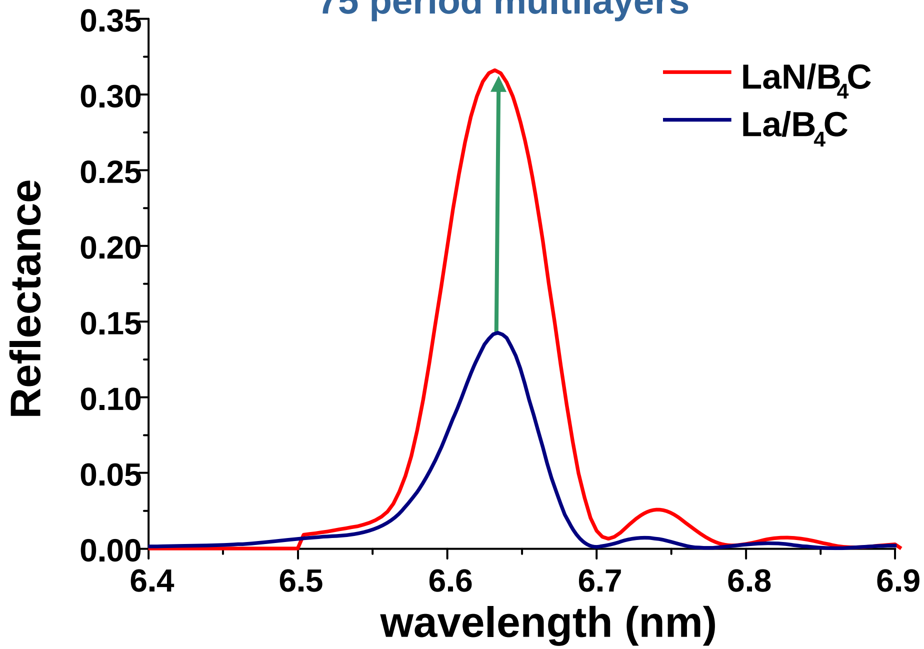
[1]T. Tsarfati, E. Louis, F. Bijkerk, et. all., Thin Solid Films 518, 24, 7249-7252 (2010)

How does LaN perform in reflectance?

Reconstruction of La depth profile



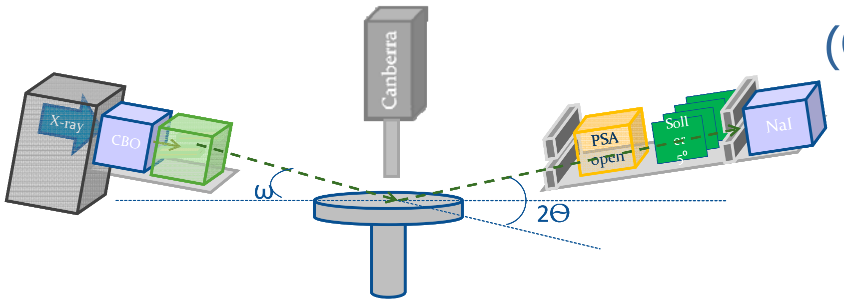
75 period multilayers



Dramatic difference in maximum reflectance

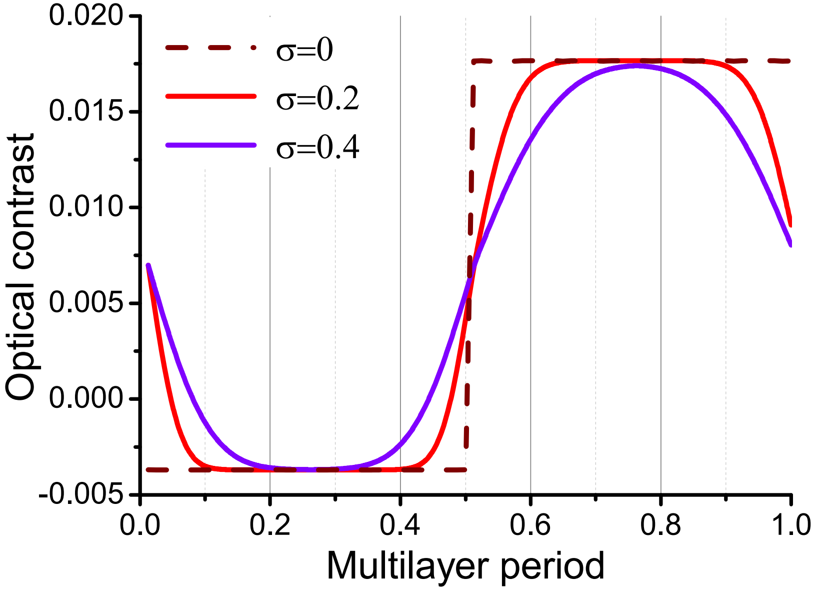
Without any process optimization

(Only 75 period multilayers)



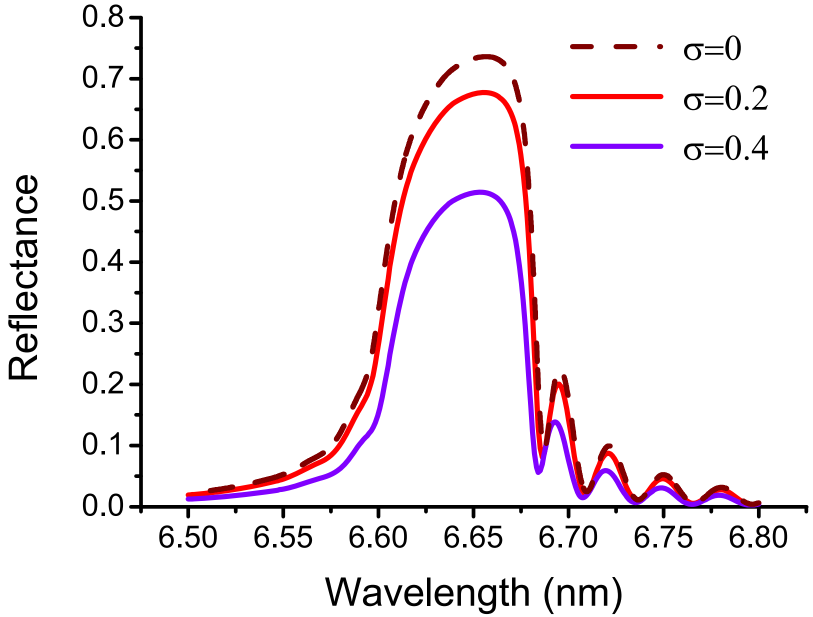
Nitridation of La →
key to reducing layer
intermixing

2^{nd} challenge: roughness reduction



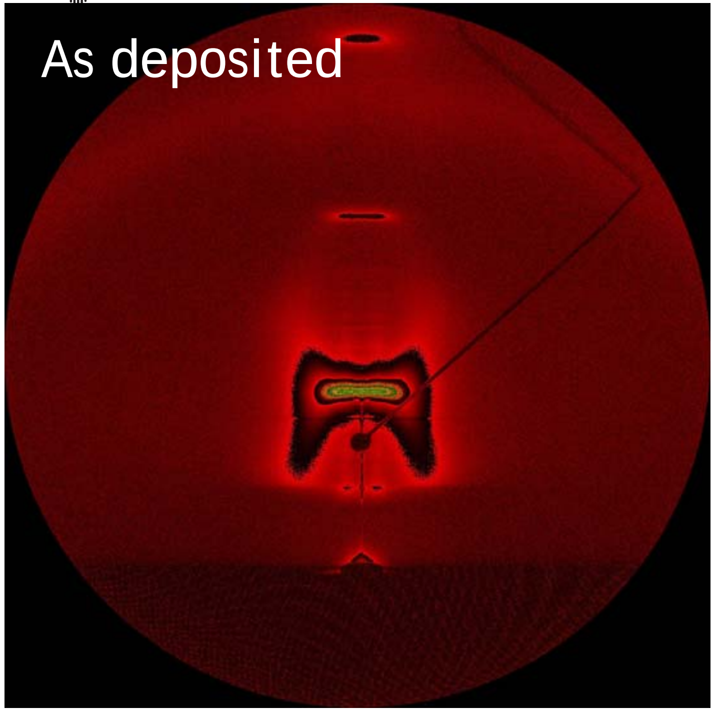
Calculations for 200 period LaN/B_4C multilayer:

Roughness (σ) reduction from 0.4 to 0.2 nm → significant reflectivity gain



Roughness control is essential

Scattering from interfaces



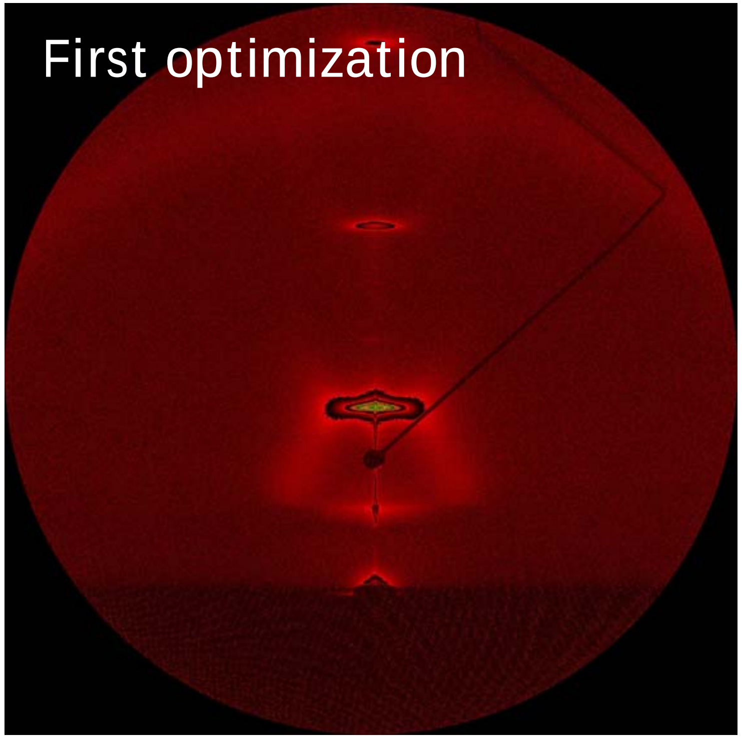
→ Individual interface roughness: 0.3-0.6 nm

→ No severe increase roughness with number of layers

Growth optimization

- →Smoothing mechanisms
- →Kinetic growth manipulation

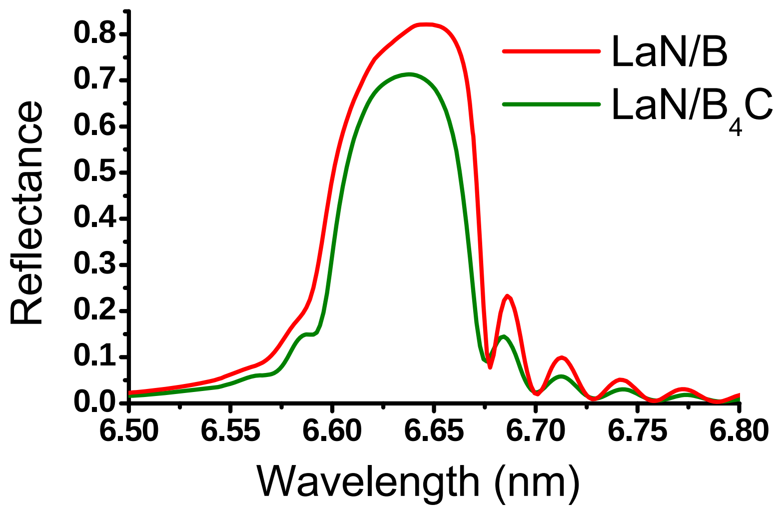
Process optimization → smoother interfaces

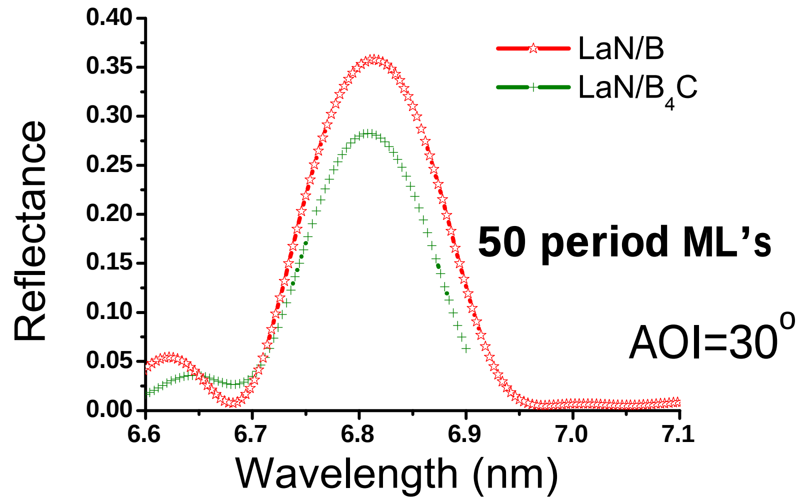


3rd challenge: optimal optical contrast

Replacement B_4C→B: enhancement of the optical contrast

200 period ML's





Calculations on ideal multilayers using measured[1,2] optical constants:

→ 10% reflectivity gain

Measurements of pilot samples confirm reflectivity gain

→ Deposition pure B to be optimized

Replacement of B_4C with B → reflectivity gain expected

1. R. Soufli et. al., Appl. Opt., Vol. 47, 25, 2008
2. M. Fernandez-Perea et. al., J. Opt. Soc. Am. A, Vol. 24, 12, 2007

Outline

- FOM, who we are …
  - → 14 years of extensive 13.5 nm research
  - → Coating research is essential key to new generation

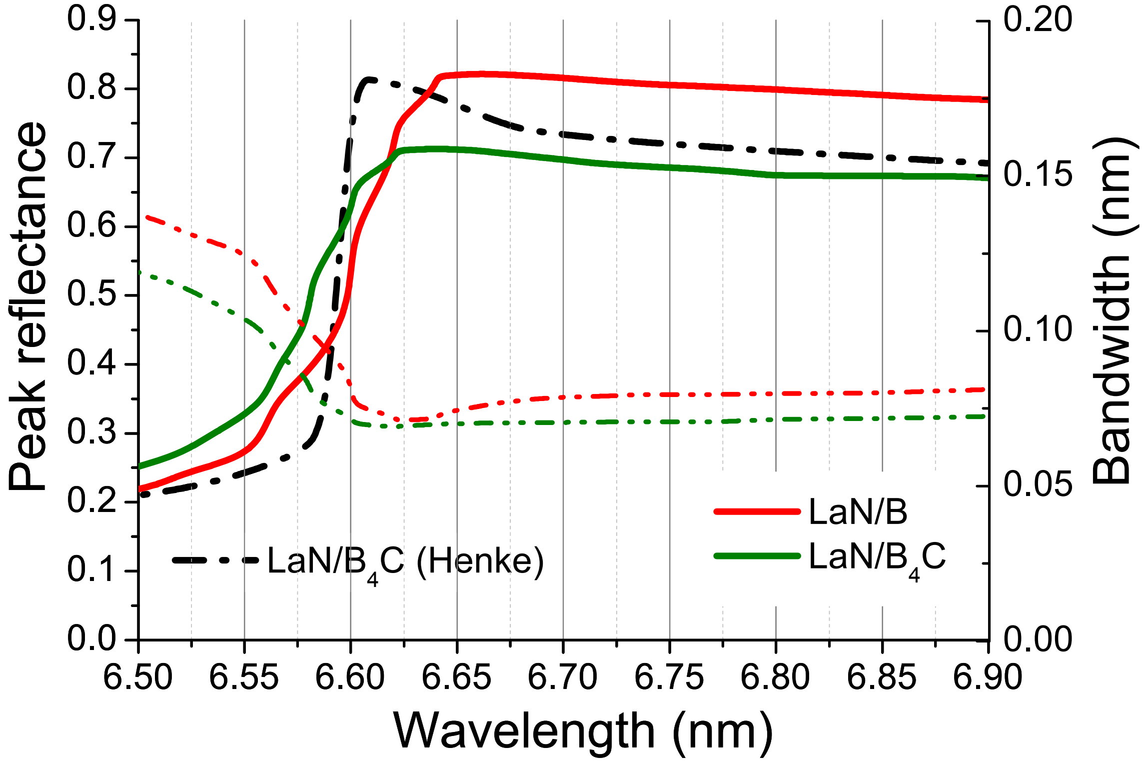
- 6.x multilayer issues (a.o. materials) to determine performance and optimum operational wavelength
  - Passivation of La with Nitrogen
  - Roughness reduction
  - $B_4C \rightarrow B$

- Wavelength selection: multilayer reflectivity profile @ 6.5-6.9 nm

Calculated multilayer reflectance

Optical constants:

- **R. Soufli et. al., Appl. Opt., Vol. 47, 25, 2008**
- **M. Fernandez-Perea et. al., J. Opt. Soc. Am. A, Vol. 24, 12, 2007**

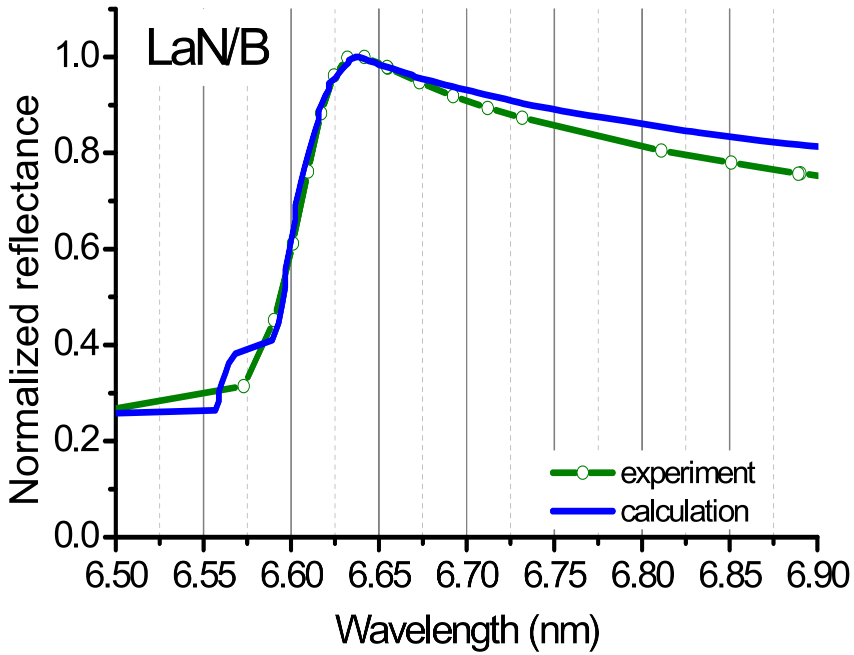


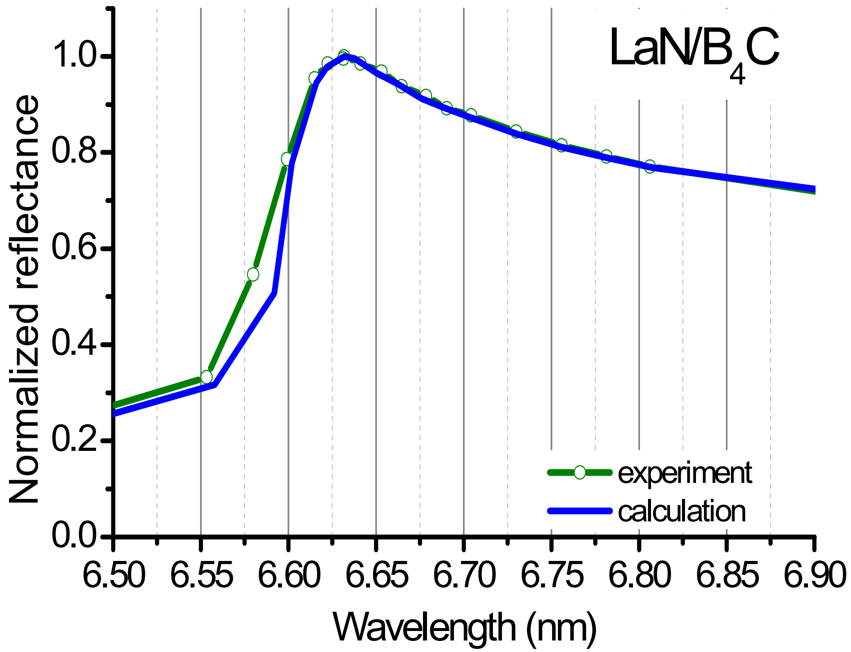
Perfect multilayer: → LaN/B: maximum reflectance at 6.66 nm

→ LaN/B_4C: maximum reflectance at 6.63 nm

Can optical constants be trusted?

R(λ) measured at various angles of incidence





Calculated maximum confirmed by measured data →
optical constants reliably predicts optimal wavelength!

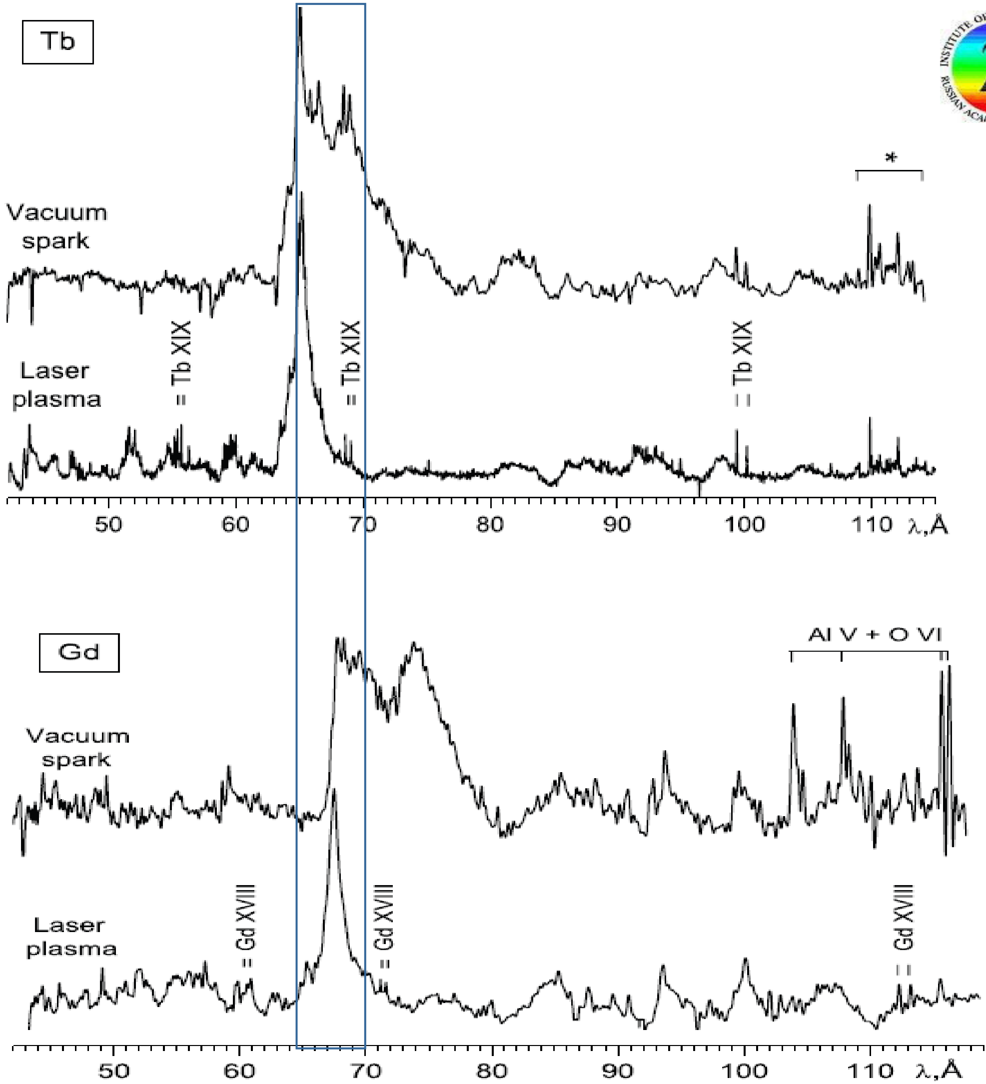
What about the source?

Determination wavelength 6.x nm lithography:

Simultaneous optimization required:

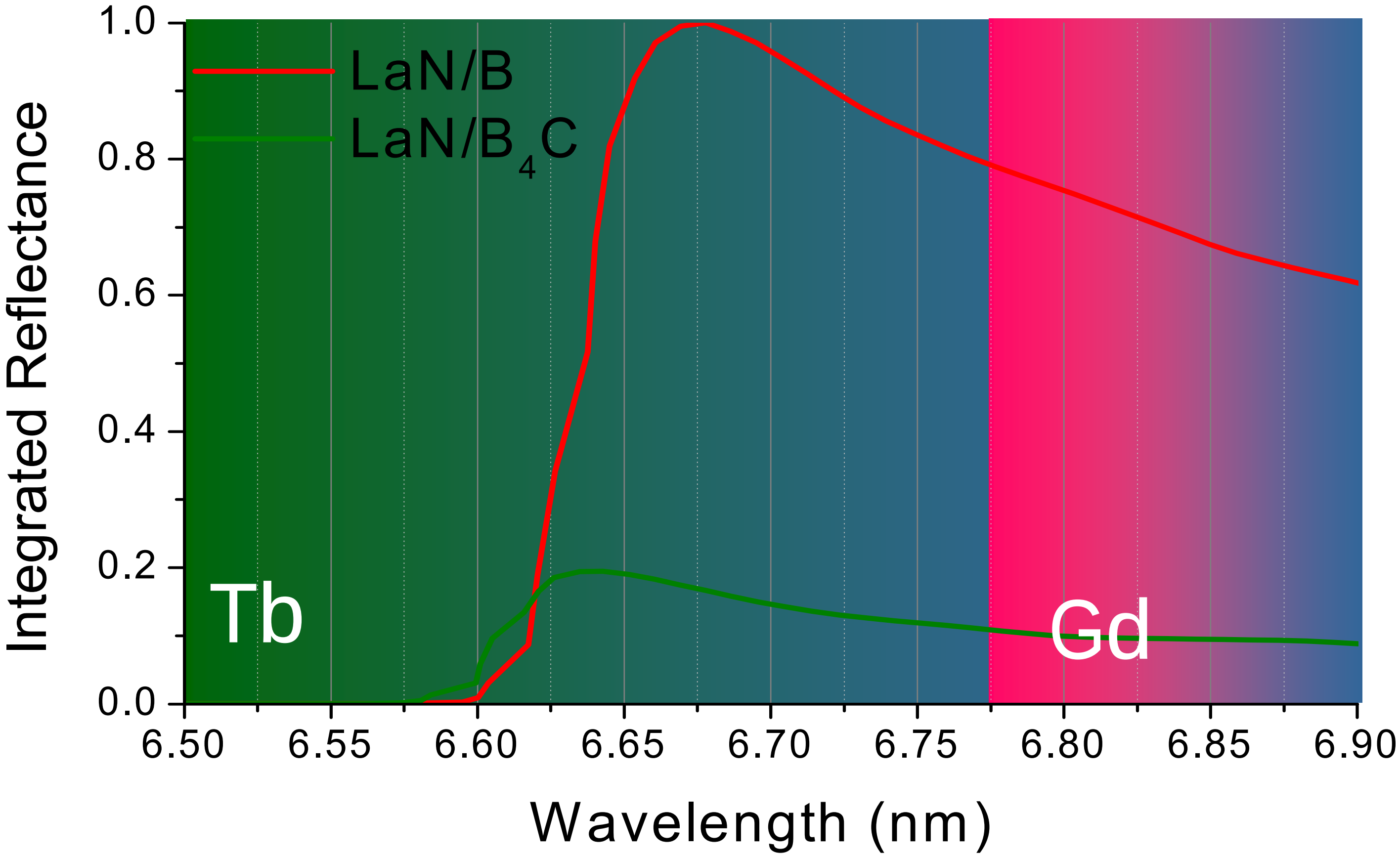
- source
- multilayer performance
- optical design

Candidate wavelength band: 6.5-7.0 nm



S.S. Churilov et al., Phys. Scr. 80 (2009)

Throughput of a 10 mirror system



Significantly larger throughput for LaN/B based optics !

Optimal wavelength: LaN/B_4C: λ=6.64 nm; LaN/B: λ=6.67 nm

Based on 10 ML reflectivity: Tb λ > 6.63 nm; Gd λ > 6.78 nm

Conclusions

- La-B interdiffusion strongly suppressed by nitridation: La/B_4C → LaN/B_4C

- LaN/B_4C → LaN/B enhanced reflectance
  → experimentally confirmed

- Preferred multilayer wavelength value: 6.63 nm or higher

- LaN/B 10 mirror system: highest throughput at 6.67 nm

- Source: Tb: λ > 6.63 nm
  Gd: λ > 6.78 nm
  → Choice to be made also by source arguments

Acknowledgements

Coworkers at FOM and ZEISS and ASML

Dutch Technology Foundation stw

The team at PTB Berlin

The team at Kurchatov Institute Moscow,

DESY Hamburg and

Institute of Crystallography RAS Moscow.

Thank you!